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Review of wallowing in pigs: implications for animal welfare

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Abstract

Most modern production systems, especially in temperate climates, do not offer wallowing facilities to pigs and, to date, this has neither generated much concern in welfare science nor public debate on pig welfare. Nevertheless, wallowing is a natural behaviour of pigs which may be important to them. This paper systematically examines the overall importance of wallowing for pig welfare using principles developed in semantic modelling. As a first step, relevant citations were collected from the scientific literature. Secondly, since the importance of the attribute ('wallowing') is dependent upon the discrepancy between its best and worst levels, these levels were specified in relation to the status quo *in pig husbandry, ie no pool (even during periods of overheating) and the ideal mud pool, respectively. Criteria for an ideal mud pool were formulated in terms of pool location and size, substrate, thermal conditions, body care and hygiene. Thirdly, available scientific information about wallowing was systematically described in relation to ten so-called weighting categories identified in semantic modelling (pain and illness, survival/heat stress, fitness, stress, aggression, abnormal behaviour, frustration, natural behaviour, preferences and demand). Fourthly, the welfare importance of wallowing was assessed by tentatively comparing it to several other welfare attributes, such as food, foraging substrate, social contact and non-castration. This leads to the suggestion that wallowing is important for pig welfare because of its multifaceted nature. It may even be very important when other forms of thermoregulation are sub-optimal. This paper, finally, discusses the 'ethical room for manoeuvre' concerning the (non-) implementation of mud pools in practice. An integrated approach is suggested to address related scientific, technological and ethical issues, because stakeholders are faced not only with scientific and technological gaps in knowledge but also with economical, ecological, food-safety and psychological barriers. As an important element of natural behaviour and positive welfare, the subject may provide an opportunity for pig farming. This should be recognised more explicitly in transition processes towards fully sustainable pig production systems.*

Keywords: *animal welfare, ethics, natural behaviour, pigs, semantic modelling, wallowing behaviour*

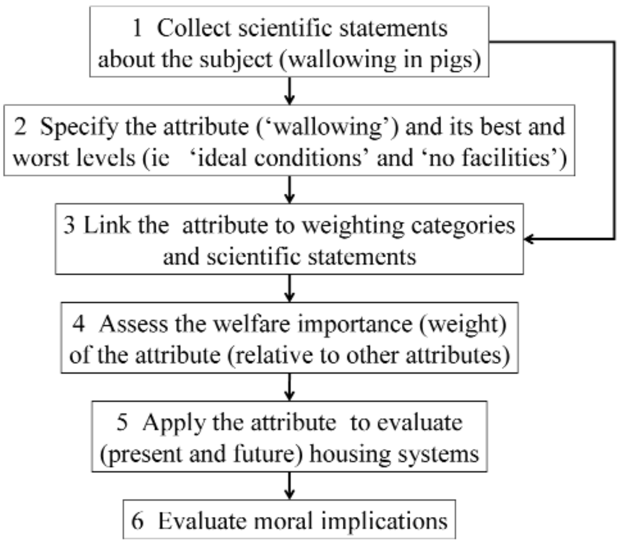
Introduction

This paper addresses the question: how important is wallowing for pig welfare?

For practical welfare evaluation, the concept of the Five Freedoms has been formulated (FAWC 2009). The Five Freedoms are, in an abbreviated form: (1) freedom from hunger and thirst; (2) freedom from discomfort; (3) freedom from pain, injury and disease; (4) freedom to express normal behaviour; and (5) freedom from fear and distress. Given these formulations, wallowing may be considered important because it may help to reduce heat stress and ectoparasite levels (eg Sambraus 1981; Van Putten 2000). As such, wallowing could load on welfare through the second, third and fifth freedom (discomfort, disease and distress, respectively). However, since farmed pigs are normally kept in thermocontrolled environments and are treated when suffering from ectoparasites, wallowing may not be important for pig welfare under these freedoms. Wallowing may also be important under the fourth freedom (normal behaviour). Here, again, it is not clear whether wallowing would classify. Wallowing is a normal behaviour of pigs in (semi-) natural environments, but its absence in most modern production systems may also be regarded as normal. By contrast, the Dutch Ministry interprets this freedom as 'Freedom to express natural, species-specific behaviour' (LNV 2007). This formulation would seem to include wallowing, and consequently require 'protection'. At present, however, wallowing is not an issue of concern (Leenstra *et al* 2007; Cornelissen *et al* 2009), even in new designs for welfare-friendly and sustainable pig farms in the future (Van der Peet *et al* 2010; Van Eijk *et al* 2010a,b;). De Greef *et al* (2003) stated, for example, that the environment should be such that wallowing is not necessary, perhaps implying that wallowing facilities are undesirable. Others, however, suggested that wallowing may be important (Sambraus 1981; Van Putten 2000; McGlone, personal communication 2010).

A more detailed scientific review, therefore, is needed to examine the welfare importance of wallowing for pigs. This paper will seek to do so using semantic-modelling princi-

Figure 1



Steps taken to assess the welfare importance of wallowing in pigs. Underlying scientific statements (Step 1) were collected in Bracke (2010). Semantic modelling formally concerns steps 1 to 5, where steps 4 and 5 are presented in this paper only as an illustration of the methodology. Weighting categories define different types of welfare performance measures, such as 'stress', 'frustration' and 'demand'.

ples. Semantic modelling is a relatively new approach to systematically assess the welfare importance of welfare attributes (such as 'space', 'social contact' and 'wallowing') based on available scientific information. The method has been developed by the first author (Anonymous 2001; Bracke *et al* 2002a; Bracke 2008) and others (eg Ursinus *et al* 2009; www.imr.no/salmowa; for an overview see Bracke *et al* 2008). Semantic modelling offers benefits in terms of making welfare assessment more formalised and (semi-) quantitative. Previously, semantic modelling has been criticised for confirming what was already known, as it repeatedly showed high correlations with expert opinion (Bracke *et al* 2008). Wallowing has received relatively little attention, and the importance of wallowing for animal welfare is not clear. The application of semantic modelling principles to wallowing in pigs may, therefore, provide insights not previously offered by consensus opinion in animal-welfare science. At the same time, it provides a further illustration of (semi-) formalised welfare assessment using semantic-modelling principles (see also Bracke 2008; Bracke *et al* 2008), and it provides an opportunity to revisit the previous suggestion that wallowing is not very important (Bracke *et al* 2002a,b).

The SOWEL model, designed to assess overall welfare of pregnant sows at the housing-system level, contained 'wallowing' as one of 37 attributes (Bracke *et al* 2002a). This attribute (with best and worst levels 'mud pool' and 'no mud pool', respectively) received a low weighting, both in the model (4.6 on a scale ranging from 2.4 to 25.8) and according to 23 international pig-welfare scientists (Bracke *et al* 2002b). Two main reasons account for this. Firstly, for modelling, a limited knowledge base was used (especially SVC 1997). Secondly, since 'wallowing' was part of an overall welfare model, it was (tentatively) defined excluding its main related functions, such as thermoregulation and scratching of the body (which were already covered by other attributes in the model). A more detailed review of wallowing has indicated that wallowing is a complex behaviour probably involving various interrelated motivations (Bracke 2011). As a consequence, the overall welfare impact of wallowing *in optima forma*, which is the subject of this paper, may be much higher than previous modelling has suggested.

A formalised welfare assessment of wallowing is important to support ethical and political decision-making. At present, a substantial discrepancy exists between modern pig production using relatively barren concrete pens and public opinion valuing outdoor access and wallowing in mud (cf Lassen *et al* 2006). As a consequence, wallowing is a very sensitive subject. This restricts the 'ethical room for manoeuvre' of stakeholders who wish to provide wallowing facilities for pigs. Since this may interfere with innovations, alternative ways to deal with this need to be examined.

The primary objective of this paper is to assess the overall importance of wallowing for pig welfare based on semantic-modelling principles. To this end, criteria are formulated for the ideal mud pool for pigs, the available information about wallowing is presented systematically and the overall importance of wallowing is assessed in a tentative comparison to several other pig-welfare attributes ('Food', 'Foraging substrate', 'Social contact' and 'No castration'). Areas of further research and ethical implications in relation to 'ethical room for manoeuvre' are also briefly discussed.

Materials and methods

The underlying premise of semantic modelling is that an assessment of the welfare importance of an attribute, such as the provision of adequate wallowing facilities for pigs, must be based on scientific information describing relationships between so-called design parameters (eg presence/absence of a mud pool, ambient temperature) and welfare-performance measures (eg panting, feed intake and mortality). Figure 1 presents the steps involved.

Step 1 was conducted in May 2010 when an internet literature search was carried out, primarily using Google Scholar® and Scopus® as a first entry, later supplemented with searches in CAB abstracts and Agricola®, and searching for the keywords: 'wallow', 'mud', 'pigs', 'hogs' and 'swine'. From the references obtained, citations about wallowing in pigs and related species were extracted. As a working definition, wallowing was specified as covering (part of) the body surface with mud or a mud-like substance. Citations were presented in the Annex of the underlying report (Bracke 2010). In addition, wallowing behaviour and motivations for wallowing were reviewed in a separate paper (Bracke 2011). These publications (Bracke 2010, 2011) provided the basis for the formalised review presented here (for other formalised reviews in semantic modelling, see Bracke *et al* 2004, 2006).

In Step 2, which is presented in the next section of this paper, the subject ('wallowing in pigs') was specified as an attribute ('wallowing'). An attribute's weight depends on the scope of the assessment domain, which in this paper is widely defined, ranging from intensive pig farming to living in a fully natural environment (with presumably ideal mud pools), but also from unfavourable to favourable climatic conditions. To specify the assessment scope, the best and worst levels of the attribute must be formulated. The 'worst level' was formulated in close relation to the current husbandry system. Criteria for the ideal mud pool were derived from the scientific citations.

In Step 3 (section entitled *Impact of wallowing on weighting categories*), 'wallowing' was systematically reviewed in terms of welfare performance. For this, ten so-called weighting categories were used: pain and illness, survival, fitness, stress, aggression, abnormal behaviour, frustration and avoidance, natural behaviour, preferences and demand (Bracke *et al* 2002a). These measures, which were originally formulated to assess the overall welfare status of pregnant sows, together cover the disciplines in which animal welfare is studied.

In Step 4 (*Importance of wallowing for pig welfare*) the available information has been integrated. For this, the general rule was used that information about health (pain, illness, survival), stress and demand is more important than mere indications about behavioural modifications (see Bracke *et al* 2002a). In a formal assessment, an attribute's weight is derived from a comparison with other attributes, where the weight of each attribute is a function of the difference in welfare relevance between its best and worst levels. Other attributes are needed as positive and negative 'controls' to specify the range of the scale used to assess welfare importance (ie an ordinal scale, ranging from 'not at all important' to 'crucially important'). This paper did not allow the (semi-) quantified expression of the importance of wallowing, because it did not include a formal assessment of other welfare attributes against which wallowing could be compared. However, the principles are illustrated in a comparison to the attributes, 'Food', 'Foraging substrate', 'Social contact' and 'No castration'. To this end, tentative plus (+) and minus (–) 'scores' were attributed for each weighting category. The scores express how information about welfare-performance measures are related to the incidence, duration and intensity (Willeberg 1991) of presumed underlying emotional and motivational states. These represent the pleasure/happiness and suffering that together define the animal's welfare, ie its quality of life as perceived by the animal itself (Bracke *et al* 1999).

In Step 5, present and future housing systems may be assessed formally using the modelled attribute(s). This step is only discussed provisionally in this paper with respect to the current pig husbandry system in The Netherlands (*Wallowing in current pig husbandry*), in part because only limited information is available and because improved wallowing facilities remain to be developed.

Finally, in Step 6, the implications are discussed in a wider ethical context. This step is not formally part of semantic modelling, because the modelling aims to provide best-possible descriptive assessments of welfare based on scientific knowledge (eg how important wallowing is for pig welfare). By contrast, ethics deals with ought-statements (eg whether wallowing facilities ought to be provided to pigs). This paper proposes a new way of dealing with sensitive issues, such as wallowing in pigs, based on the notion of 'ethical room for manoeuvre' (Korthals 2004, 2008a,b; Driessen 2007).

Attribute specification: ideal mud pool and *status quo*

In order to assess the overall welfare importance of wallowing in pigs, the best and worst possible levels of the attribute must be characterised against the background of what would be ideal for pig welfare and what is their current welfare status.

'*Status quo*'

The worst possible level that is relevant for the assessment relates to the '*status quo*' under which most pigs are presently housed (without mud pool).

Compared to the situation with ideal wallowing provisions, the worst-possible level of the attribute 'wallowing' may be characterised as a situation where few or no possibilities for wallowing exist. Pigs are normally kept at temperatures recommended for production purposes, but hot periods occur during which pigs have reduced growth rates and increased mortality rates (partly) due to heat stress (McGlone 1999). Pigs rest on hard concrete floors. Water is available from nipples or drinking cups installed above slatted floors. This (largely) prevents animals from lying on a wet floor. Wallowing in faeces is also limited (eg because of slatted-floor systems and other measures taken to avoid pigs from lying in their own dung). Pen walls are smooth, limiting the possibility for scratching and rubbing (body care). Ectoparasites and 'biting' insects, such as mosquitoes and flies are present. Water is available *ad libitum* and food is provided at levels that meet nutritional requirements. This is (close to) *ad libitum* for lactating sows, weaned piglets, growing pigs and fattening pigs, and restricted (about 60% of *ad libitum*) for pregnant sows. Space per growing/finishing pig is below 1 m^2 per animal, and for sows below 2.5 m^2. Since no substrate is provided, limited opportunities exist for exploration and foraging behaviours. Rooting, in particular, is virtually impossible.

Ideal mud pool

The best possible level of the attribute 'wallowing' can be derived from specific recommendations on wallowing provided in the literature as well as from citations describing and explaining wallowing behaviour in pigs generally (collected in the Annex of Bracke 2010).

The criteria have been grouped into the following subsections:

- Wallow location and size;
- Wallowing substrate: mud and water;
- Temperature;
- Behaviours related to wallowing;
- Body care;
- Hygiene.

Location and size

According to McGlone (1999), wallows should be large enough to accommodate twice the size of the number of pigs in the group. This accommodates for communal wallowing and ensures access for the submissive animals (McGlone 1999). Wallowing facilities should also allow for individual wallowing (Stegeman 1938). Easy access for all animals is important. Dellmeier and Friend (1991) suggested this may be achieved by a central location of the wallow in the enclosure. Sufficient border space is important as this is preferred by the pigs. In these areas, the mud and water levels are not higher than the elbow joint (Sambraus 1981). Wallows have both more shallow and deeper areas to accommodate different wallowing needs at different temperatures (standing in cool water when it is slightly warm; sitting; rolling, immersing themselves when it gets warmer; McGlone 1999). Pigs should be able to keep their ear-openings above the water/mud surface (Sambraus 1981). In order to keep water in the wallow, wallows may best be located in low-lying, wet areas (Dickson *et al* 2001).

Wallowing substrate: mud and water

Natural wallows are depressions in mud, also filled with water (Campbell & Long 2009). They are created by loafing, rolling and rooting of pigs in moist soil (Stevens 1996). Wallows should look like a pond and not simply contain thick mud (McGlone 1999). Mud is preferred over water for cooling (Ingram 1965; Jensen 2002). An ideal mud wallow leaves a heavy coat of mud when it is very warm (McGlone 1999).

Ambient temperature

Ideally, wallows should be present at all times, because pigs may wallow at all temperatures above freezing, depending on variables, such as illness (Sambraus 1981), oestrus cycle (as sows wallow more when in heat; Sambraus 1981) and heat-producing activities (Stegeman 1938; Graves 1984; Vestergaard & Bjerg 1996).

Different publications suggest somewhat different temperatures at which wallows should be available (over 21.1°C: Heitman *et al* 1962; above 20°C: Jensen 2002; above 18°C: Stolba & Wood-Gush 1989; above 15°C: Olsen *et al* 2001). Dellmeier and Friend (1991) suggested that slaughter pigs (> 90 kg) may benefit from a wallow at temperatures above 17°C. Below 12°C, pregnant sows did not appear to use wallows regularly (Sambraus 1981), but wild boar will wallow also at colder temperature ranges and during rain (Frädrich 1967) and domestic pigs will also incidentally use wallows at very low temperatures (Buckner *et al* 1998; even around freezing, McGlone, personal communication 2010). Some authors indicated that wallows should be shaded (Stegeman 1938; Dellmeier & Friend 1991). McGlone (1999) recommended shaded wallows during very hot weather (providing wallows > 35.5°C under arid [dry] conditions; > 27°C in humid conditions), and he recommended providing (unshaded) wallows as of 21.5°C and 21°C in dry and humid conditions, respectively. McGlone (1999) also stated that during hot and very hot weather, pigs should stay in the wallow as much as possible, leaving only for feeding and, for example, nursing.

An ideal wallow should be cool during warm weather (McGlone 1999), and perhaps warm during colder weather. During very hot weather, inflow of fresh water may help prevent water lines from becoming very hot (McGlone 1999). At all times, but especially during cooler days, a separate dry and comfortable lying area is important, and, more generally, pigs require opportunities to be able to warm up after wallowing should they prefer to do so.

Behaviours related to wallowing

Pigs should be able to dig and root in mud before entering the pool (Jensen 2002). An ideal wallow allows for various posture changes (and provides sufficient grip; Olsen *et al* 2001). Ideally, the wallow is available all day, particularly immediately after feeding (Sambraus 1981). Pigs will use wallows several times per day (Stevens 1996). An ideal pool provides a comfortable resting area and opportunities for body care/comfort behaviours.

Body care

Under semi-natural conditions, rubbing posts are generally found near wallows and at other places in the enclosure (Stegeman 1938). This includes opportunities for various kinds of rubbing (anogenital rub; side rub; head rub). To this end, a tree and stone next to the pool may suffice (Jensen 2002). Scratch posts that have been used extensively show signs of mud up to the height of the tallest animal in the group (Stegeman 1938). Pitch pines less than 15 cm in diameter appear to be preferred under natural conditions (Stegeman 1938; Graves 1984). Others report that creosote-treated posts were preferred perhaps as an aid in ectoparasite control (Stevens 1996; Dickson *et al* 2001).

Hygiene

Pool hygiene is important. Pigs should not ingest wallow-water contaminated with excreta. This may be regulated by the pigs themselves (Sambraus 1981; Dellmeier & Friend 1991) or by management measures, such as regular cleaning of wallows, disinfection of wallow water (Van Putten 2000), locating wallows away from the (designated) excretion area (Huynh *et al* 2006) and/or providing fresh (drinking) water in/near the wallow (Dellmeier & Friend 1991; McGlone 1999). McGlone (1999), for instance, recommended providing fresh water in the wallow, eg by continuously dripping or streaming fresh water over the wallow. Older references provided several (mostly outdated) recommendations on ensuring pool hygiene (eg Day 1915; Imes 1920). Abell (1947), interestingly, suggested that the morning sun should be allowed to penetrate beneath shade trees and reach the wallow surface, because wallows on accumulations of damp, dead leaves beneath trees are possible sources of infection by worm parasites. Ideally, pigs should also be allowed to defaecate and urinate near or perhaps even in the pool (Sambraus 1981; Olsen *et al* 2001; see also the sections below on *Fitness* and *Abnormal behaviour*).

Impact of wallowing on weighting categories

The importance of wallowing can be derived from scientific information about welfare-performance measures, which have been classified as weighting categories in semantic modelling. The weighting categories are discussed in the sections below in the order in which they were first formulated. This is roughly in the order of their general potential for welfare loading (Bracke *et al* 2002a). The more welfare-relevant benefits are associated with wallowing, the more important the attribute ('wallowing') is for pig welfare. At the end of each weighting category, a tentative score is given for comparison with several other attributes in the next section.

Pain and illness

While pain and illness are potentially important indictors of poor welfare, little evidence was found of relationships with wallowing. As reviewed in Bracke (2011), wallowing in mud has been ascribed several functions, some of which relate to pain (sunburn protection) and others to disease (wound healing, protection from ectoparasites, heat stroke, cooling during general illness). Where applicable, these different functions contribute to the welfare importance of wallowing *in optima forma*. The weighting categories, 'pain' and 'health' may also be negatively affected by wallowing, especially when wallowing conditions are not optimal (eg excessive wallowing may perhaps result in lameness, see *Fitness* section, and gastro-intestinal illness could arise from soiled pools, see *Hygiene*). Since the objective of this paper is to assess the importance of wallowing *in optima forma*, these latter aspects are not included in the overall weighting. Overall, this weighting category generates a tentative negative loading on the attribute 'wallowing' ('-?' in Table 2). In other words, wallowing may tentatively contribute to the alleviation of pain and illness.

Survival: heat stress

This section describes impacts of wallowing on survival *per se*. Since this mainly concerns thermoregulatory problems, it was decided to include heat stress and related signs of thermal discomfort in this section. Subheadings include effects on behaviour (activity), respiration, skin and body temperature, production and survival *per se*. Note that production was originally subsumed under the weighting category 'fitness' (Bracke *et al* 2002a). However, since the effects of wallowing on production are likely to be related to heat stress, it was decided to include production in this paragraph. Overall, wallowing appears to have significant thermoregulatory benefits for pigs. Whether or not this is actually the case depends on the pigs' exposure to thermal conditions (discussed in the section on *Wallowing in current pig husbandry*). Overall, this weighting category is estimated to have a fairly considerable negative loading ('--' in Table 2).

Behaviour

Wallowing may increase general activity levels during periods of hot weather (Dellmeier & Friend 1991). While increased activity (other than increased feeding) is generally unwanted for production purposes (as it reduces the amount of energy that can be spent on production), increased activity is usually good for welfare, provided the environment is suited to accommodate the (normal and natural) behaviour patterns of the animals (as is the case in an ideal/'good welfare' situation; Bracke 2007).

Respiration

Wallowing reduces elevated respiration rates due to (over-) heating. Indoor-housed sows with drip cooling had consistently higher respiratory rates than outdoor sows with access to mud wallows, implying that outdoor mud wallows provide a much more effective cooling substrate (McGlone 1999). Since increased respiratory rates require extra heat production (Mount 1979), pigs prefer wallowing to cope with high temperatures, especially at elevated relative humidities (Huynh *et al* 2007). Ingram (1965) showed that a wetted skin with water can evaporate water very effectively. Thus, wallowing is more comfortable for the animals compared to increased panting.

Skin and body temperature

Wallowing may reduce skin and body temperature. Huynh *et al* (2007) exposed growing gilts with an initial bodyweight of 62 kg to 16°C with a 2°C increase per day, ending at 32°C. Relative humidity was set at 50, 65 or 80% and remained constant. Skin temperature was lowest at 80% relative humidity. For each degree Celsius rise in skin temperature, wallowing in dung increased by 0.19%. For each degree Celsius rise in ambient temperature (between 16 and 32°C), total heat production decreased by 115 kJ pig^{-1} day^{-1} and evaporative heat loss increased by 290 kJ pig^{-1} day^{-1}. Under constant high ambient temperature and relative humidity, the pigs clearly employ respiratory evaporation to lose heat. The importance of skin evaporative heat loss through wallowing was clearly evident with higher temperatures, especially at high relative humidity. At this condition, pigs should be able to wet their skin (Huynh *et al* 2007). These authors also showed that, especially at higher relative humidity (80%), pigs were wallowing in excreta long before respiratory rates went up (wallowing in excreta already increased at 18°C in growing/finishing pigs).

Furthermore, pigs on pasture without wallows had elevated body temperatures as high as 41°C on hot days, whereas similarly housed pigs with access to wallows had body temperatures between 39 and 40°C (Bray & Singletary 1948). When sows are kept outdoors, heat starts to accumulate in the body when the environmental temperature rises above about 20°C, and this increases the need to cool by wallowing (Sambraus 1981).

Production

Wallowing may increase productivity (eg Tidwell & Fletcher 1951; Dellmeier & Friend 1991), and it allows pigs to maintain productivity that would otherwise be lost, especially at times of acclimatisation to high ambient temperatures (Fraser 1970).

Pigs maintained at high temperatures have a decreased feed consumption and delayed return to oestrous (SVC 1997). Wallowing can counteract these effects. Culver *et al* (1960) noted:

> Jackson (1938) was one of the first to submit data showing that at temperatures above 83 F [28.3°C] the use of a swine wallow increased appetite, rate of gain, and efficiency of feed utilization. Bray and Singletary (1948) showed that in hogs being fattened on pasture in Louisiana the use of a wallow increased daily gains nearly 0.40 lb [200 g] per pig during a 73-day period. … The use of a wallow [in our studies] increased rate of gain in one of two experiments. […] The use of a wallow reduced the rise in respiration rate, but was not as effective as a spray, especially at temperatures above 83 F.

Heitman *et al* (1959) showed that wallows (with or without shade or additional air flow) increased productivity in growing/finishing pigs when exposed to temperatures up to 35°C (as did access to an air-conditioned house).

Results obtained by Garrett *et al* (1960) over a three-year period in which comparisons were made of pigs' response in a naturally hot environment (mean daily temperature 32.7°C) modified only by the use of either a shaded or unshaded wallow (all animals had access to other shade), indicated consistent and significant increases in average daily gain and daily feed consumption for pigs provided with the shaded wallow. Rectal temperatures and respiration rates were higher for pigs with the unshaded wallow. Wallow water temperature during the hottest part of the day (1000 to 1700h) averaged 12°C lower in the shaded wallow. Comparatively little use was made of the unshaded wallow after the water temperature reached 35°C (Garrett *et al* 1960).

More recently, Anindita Panja Patel *et al* (2008) compared water sprays, water wallows and mud wallows for weaned piglets. They found that the daily water requirement was highest for water sprays and that weekly feed intake was highest in the (mud) wallows. These authors recommended mud wallows to ameliorate heat stress in piglets. Also, Gnanaraj *et al* (2008) reported significantly improved growth rates and feed-conversion ratios in weaned piglets provided with mud wallows compared to water wallows and water sprays.

These citations indicate that wallowing can increase productivity (which is here indicating enhanced biological functioning) in pigs kept at elevated temperatures. (Note that further discussion of alternative cooling methods is not relevant here as the objective of this paper is to assess the overall welfare impact of wallowing).

Survival per se

Wallowing can prevent pigs from dying due to heat stroke and heat stress.

Pigs with limited experience of exposure to direct solar radiation are highly prone to heat stroke when suddenly exposed to warm sunshine (Fraser 1970). In the swine breeding herd of the University of Ibadan, Nigeria, heat stroke occurred only in pregnant sows and only during the hottest season of the year. As a general rule, pregnant sows are more susceptible than non-pregnant females (Steinbach 1970). Sows have elevated heat production levels shortly before farrowing, and will then use wallows the most (Buckner *et al* 1998).

From the moment of birth, the wild boar has serious problems eliminating heat. At 38°C, domestic pigs may die if deprived of skin-wetting opportunities (Curtis *et al* 2001, cited in Fernández-Llario 2005). Pigs do not have functional sweat glands and their subcutaneous fat may strongly inhibit heat exchange (Heitman & Hughes 1949), resulting in a circulatory collapse (Sambraus 1981), to which domestic pigs have become highly susceptible due to selective breeding (Hörning *et al* 1999). As to survival, Frädrich (1969) stated that domestic pigs are remarkably capable of surviving in the wild, behaving exactly like wild animals. This includes wallowing, which this author regarded as a requirement for survival in the wild. Fraser (1970) noted that wallowing permits pigs, such as breeding sows, to graze and forage actively in an environment which otherwise could not be utilised by the pigs. Wallowing, therefore, is an essential element in the survival strategy of pigs living in natural environments. It is possible that domestic pigs still perceive wallowing as an essential need, even though in fact they are able to survive and produce well without it in modern husbandry systems. In this respect, wallowing could be similar to foraging and living in social groups, both of which are important for welfare without being necessary for production.

Fitness

This section deals with (other) biological benefits and costs pigs may have from wallowing (other than the aspects related to health, survival (heat stress) and stress, which are discussed in other sections). Biological benefits have been described in detail in Bracke (2011). There, it was shown that thermoregulation is a main function of wallowing in pigs and that other fitness-supporting functions cannot be excluded, including skin care (including aiding in shedding of hair/skin and protection against sunburn, biting insects and ectoparasites), health (eg disinfection of wounds), sexual functioning (eg scent marking), social cohesion, rest, play and protection against predators (eg scent masking). In addition, wallowing probably plays a thermoregulatory role in several of these control systems, eg cooling when ill, when engaged in sexual behaviour (heat, sexual aggression), after play and when engaged in flight or fight.

Besides these (potential) biological benefits, wallowing, even when allowed '*in optima forma*', may also have biological costs, ie risks to survival and reproduction. One such risk, which pigs could be 'willing' to incur, could be a concomitant reduced ability to detect and escape from predators when engaging in (sometimes elaborate) wallowing behaviour. Another risk may arise from (incidental) wallowing at (too) low temperatures, exposing pigs to cold stress, elevated food-intake requirements and possibly increased illness. Pigs may be vulnerable to this, because of the interrelated functions of wallowing (see Bracke 2011) and because pigs are not very well able to remove (cold) wet mud from their bodies (Sambraus 1981). Finally, wallowing may impose health risks related to reduced hygiene and lameness. Incidentally, farmers report (that they expect) increased incidence of lameness when using sprinkler systems. Such risks may also be associated with (excessive) wallowing as claws may get soft from prolonged wallowing and/or exposure to wet soils or floors (but this clearly would not constitute optimal wallowing conditions).

Hygiene has been recognised as a major problem associated with wallowing (Day 1915; Smith & Hawkes 1978; Gegner 2001; Huynh *et al* 2006). Since pigs have a preference to eliminate in wet and cool places (Hacker *et al* 1994), pigs may urinate and defaecate in the wallow. In addition, they may drink from the water, hence spreading parasites, such as coccidiosis (Henry & Tokach 1995) and lungworm (Day 1915). Kaller and Kelso (2006) reported increased bacterial loads near feral-pig wallows and changed bacterial compositions of streams. Callaway *et al* (2005) found no significant differences in *Salmonella*, generic *E. coli* and coliform populations between indoor farrowing stalls and outdoor farrowing huts with wallows. Nevertheless, all eight outdoor wallows they sampled contained *Salmonella* spp and the authors suggested that the role of wallows in disseminating *Salmonella* within an outdoor swine herd may be significant (Callaway *et al* 2005). To counteract hygiene problems, the pigs themselves may be able to adopt behavioural strategies, such as elimination outside the wallowing pool and keeping the ear openings above the water level (Sambraus 1981), thereby possibly reducing the incidence of ear infections. Another example of pigs self-regulating hygiene was given by Dellmeier and Friend (1991) who reported that sows kept under extensive conditions left a wallow that contained free-standing water and walked 50 m or more up a slight incline in hot summer weather (> 32°C) to drink from a water nipple.

Since this paper concerns assessment of welfare implications of wallowing *in optima forma*, comparing the benefits of the ideal mud pool, the biological costs are probably small. In as far as they do exist, however, these risks may load on welfare in two opposing ways. By themselves, these costs may indicate reduced welfare importance of wallowing (eg when pigs suffer more from illness due to wallowing). On the other hand, however, in as far as the costs have been part of the pigs' evolutionary history, the costs may also emphasise the importance of wallowing (eg in as far as pigs prefer to wallow despite associated hygiene risks). Otherwise, the behaviour would not have 'survived' in the course of evolution and domestication (Bracke 2011). These points, however, are rather tentative. They were discussed here mainly to illustrate the principles of welfare weighting developed in semantic modelling. The main point of this section is that, despite a lack of quantitative data, wallowing appears to have considerable fitness potential (over and above dealing with elevated ambient temperatures). Overall, this weighting category is estimated to generate a tentative negative loading ('-?' in Table 2).

Stress

Wallowing can reduce signs of heat stress. Anindita Panja Patel *et al* (2009) showed that wallowing of weaned piglets in mud or water significantly reduced plasma cortisol levels compared to water spray and control groups. Also, other blood values were affected and the authors concluded that maximum relief of heat stress was observed in piglets which have access to mud wallowing, followed by water-wallowing and water-spraying treatments. Rosaline *et al* (2008), however, found no differences in faecal cortisol between groups of weaned piglets with and without wallows. Pregnant sows showed higher cortisol levels (ie HPA-axis activation) at environmental temperatures of 32°C than at 18°C (Bate & Hacker 1985). At such high temperatures they clearly seek out wallows. Vestergaard and Bjerg (1996), for example, reported that fattening pigs significantly increased wallowing at around 30°C compared to 18°C, and that a significant increase in wallowing was also found after forced movement lasting for 3 min and in groups of mixed pigs (compared to stable groups). Adam (1984) reported that newly introduced sows would stay together at first and then seek an opportunity to wallow in mud shortly afterwards. These findings indicate that wallowing may play a role in coping with various types of stress (eg in fight, flight and fright responses). Overall, this weighting category generates a tentative negative loading ('-?').

Aggression

The previous paragraph included several relationships between wallowing and mixing of pigs, in virtue of its relation to stress. Here, the same findings apply in relation to agonistic behaviour. In addition, there is some evidence that wild boar males wallow more during the rutting season, which is associated with increased fighting (Fernández-Llario 2005). Overall, this weighting category generates a tentative negative loading ('-?'), implying that wallows may be beneficial to alleviate the discomfort associated with aggression in pigs (which regularly occurs in modern pig husbandry, eg when mixing weaned piglets and sows).

Abnormal behaviour: pen soiling, vacuum behaviour, intention movements

For the purpose of this review, wallowing was defined as behaviour covering at least part of the body surface (hair and/or skin) with mud or a mud-like substance. It was not specified whether water or excreta may qualify as mud-like substances. Some authors have used the word 'wallowing' to refer explicitly to rolling in excreta (eg Huynh *et al*

2007). Others do not seem to regard this as (proper) wallowing behaviour (eg EFSA 2007a).

In housing systems for fatteners, fouling of the lying area is often observed when the ambient temperature rises above 25°C with pigs of 25 kg and above 20°C with pigs of 100 kg (EFSA 2007a). The pigs then use the dunging area, which is usually wet and made of perforated floor, for resting, as it has a greater cooling effect than the dry lying area (EFSA 2007a). Heitman and Hughes (1949) reported that at high temperatures, when one pig urinated, some of the other pigs usually wallowed in the moisture. This was also true to some extent for defaecation. The pigs turned over from time-to-time to expose their moist side. At high temperatures on a floor wetted with water, the pigs reacted quite differently. Instead of lying prostrate on their sides, they tossed from side-to-side and were very active. They gave the impression of trying to keep their wet surface exposed (Heitman & Hughes 1949). Huynh *et al* (2005) observed growing pigs on partly slatted floors at increasing ambient temperatures. With rising temperatures, pigs increased lying on the slatted floor, wallowing in excrement and increased showering of pigs with urine from other pigs and urinating while lying. These behaviours indicate a conflict between the motivation to stay clear of excrement and the (overriding) need to increase evaporative heat loss by getting wet (Huynh *et al* 2005).

Whether wallowing in excreta may be regarded as an abnormal behaviour is not fully clear. Some findings indicate that it may not be abnormal. Substantial dunging has been observed in wallows (Olsen *et al* 2001) and related species, such as deer, perform wallowing in direct association with their own excretions, possibly as a form of scent-marking/status advertisement (Kikuta & Stone 1986; Gosling & McKay 1990). Most evidence, however, suggests that wallowing in dung is abnormal and not indicative of good welfare. Excreta tend to be irritant substances, and pigs are aversive to their own dung (eg Bracke 2007). They aim to keep their bodies clean from faeces (eg Wechsler & Bachmann 1998; Spinka 2006). Sambraus (1981) reported only very limited elimination in allegedly proper mud pools. It has also been suggested that pigs will restrict wallowing in excreta to higher temperatures compared to mud (Huynh *et al* 2005). Therefore, wallowing in excreta (faeces and urine) is likely to happen only when pigs do not have more suitable wallowing substrate, such as mud, available. If so, wallowing in dung may resemble sham dustbathing, which occurs in the absence of suitable substrate and seems to be triggered by feed particles in battery cages (Olsson & Keeling 2005). It may perhaps even resemble tail biting in as far as this is exploratory behaviour that is re-directed to an inappropriate substrate (cf Bracke *et al* 2004; EFSA 2007b). In addition, wallowing in excreta may only serve a thermoregulatory function (relieving heat stress), whereas wallowing in proper mud pools may satisfy other needs as well (Aarnink, personal communication 2010).

Intensively raised pigs can often be observed 'playing' with drinking water. This may be interpreted as a sign of exploration, play, boredom or redirected foraging behaviour. It may, however, also be an intention movement indicating a motivation to wallow. Pigs will construct their own wallows when given the opportunity (Van Putten 2000). At present, no evidence exists that pigs would show (internally motivated) vacuum wallowing behaviour on a 'dry floor', such as dustbathing (Olsson & Keeling 2005). It would probably also be difficult to differentiate such behaviour (vacuum wallowing) from normal posture changes and normal resting behaviour. It is, however, also less likely that wallowing would be performed (fully) on the 'auto-pilot' (as thermal constraints, both high and low, are likely to impose more constraints on wallowing than on dustbathing). This latter point, that wallowing is less likely to be internally motivated, however, does not imply that wallowing is less important (see Jensen & Toates 1993). Overall, this weighting category generates a tentative negative loading ('-?').

Frustration and avoidance

It is not known the extent to which pigs may be frustrated when suddenly/unexpectedly prevented from wallowing and/or whether this may be reflected in a vocal or cortisol response as was shown for mink (*Mustela vison*) deprived of access to a water bath (cf Mason *et al* 2001). There is one anecdotal report that pigs may perhaps show a rebound of temporarily deprived wallowing behaviour (Horrell *et al* 2001):

> [W]hen the sows were first introduced into the paddocks. The [unringed] sows came running out, walked or ran round the paddock, started rooting and exploring immediately, and generally appeared full of the joys of release. One group [out of two groups of unringed sows] immediately set out to dig a wallow in a soft patch and many were wallowing in mud by the end of the 10-min observation period (Horrell *et al* 2001).

It is not clear, however, whether this behaviour was a direct consequence of wallowing deprivation or an indirect effect related, for example, to the increased activity (running and rooting).

Wallowing is related to dominance in pigs, indicating that pigs may regard the opportunity to wallow as a resource. For example, Hsia *et al* (1974) suggested that (exclusive) occupation by dominant animals may be one of the reasons why artificial wallows (usually provided as steel or concrete water baths) have compared less favourably to sprinklers for thermoregulation. Also, McGlone (1999) explicitly recommended that wallows should be big enough to allow access for submissive sows. Sambraus (1981), finally, reported that although dominant sows arriving at the pool would not chase away subordinates lying there, dominant sows already in the pool would retaliate against subordinates arriving later. This implies that the weighting category 'frustration and avoidance' also loads on the welfare importance of wallowing *in optima forma*. Since the amount of information is limited, the loading is relatively low and most of it would seem to relate to thermoregulation (which is already loaded under 'survival: heat stress'). Therefore, this weighting category generated a tentative negative loading ('-?').

Natural behaviour

Pigs probably know 'instinctively' how and when to wallow (Gegner 2001; Huynh *et al* 2007), while fine-tuning takes place through conditioning. Fraser (1970) stated that the construction and usage of mud wallows in free-ranging pigs was always performed in stereotyped ways and he suggested that the behaviour was instinctively determined. This suggests a challenge to the rhetoric question formulated by Curtis and Stricklin (1991): "Has a pig that's never seen a mud-hole ever imagined one? Wanted one? Needed one? Felt deprived when it didn't have one"? In line with the general observation that pigs easily feralise (Frädrich 1969), still perform their full behavioural repertoire under semi-natural conditions (Stolba & Wood-Gush 1989) and, for example, also still have rooting discs and rooting preferences to search for food and make wallows, it is likely that pigs have an evolutionary 'memory' of wallowing even though they no longer need this behaviour to survive under modern farming conditions. Domestication did not erase evolution (Sambraus 1981; Anonymous 2001). The evolutionary background of wallowing in pigs was outlined in more detail in Bracke (2011), where it was pointed out, for instance, that pigs are genetically related to other mammals that show wallowing behaviour (large megaherbivores) and to mammals that have adapted to living in water (hippopotamuses and whales). Wallowing is clearly a natural behaviour for which pigs are motivated. Overall, this weighting category generates a clearly positive loading ('++').

Preferences

Incidentally, wallowing preferences have been reported, eg that mud is preferred over water (Jensen 2002) and over dung (Huynh *et al* 2005) to roll in, and wild pigs appear to prefer pitch pines less than 15 cm in diameter for rubbing off dried mud after wallowing (Stegeman 1938). No preference studies have been performed on wallowing. In line with the previous paragraph and as explained in more detail in Bracke (2011), however, it is likely that pigs may experience positive emotions in relation to wallowing. Wallowing is in part a body-care behaviour which is probably (partly) internally motivated and pigs are inclined to seek out opportunities to wallow (eg wallowing may reduce pasture damage due to (otherwise preferred) rooting activities; Van der Mheen & Spoolder 2005). This suggests that pigs prefer to wallow (when environmental conditions allow it). Overall this weighting category generates a positive loading ('+').

Demand

Several authors have suggested that pigs are prepared to work in order to be able to wallow (eg Van Putten 2000; Horrell *et al* 2001). In fact, willingness to work is implied by the fact that they will make their own wallows when given the opportunity. For example, Belden and Pelton (1976) reported that feral pig wallows were on average 130 × 100 × 25 cm (length × width × depth); thus, each wallow required the removal of ~0.325 m^3 of sediment (Butler 1995). Wild pigs also engage in wallowing under high-risk conditions. For example, local hunters in the Cherokee National Forest, USA, reported instances of pigs breaking the ice to wallow and of pigs wallowing in streams that they crossed while being chased by hunters during the winter (Stegeman 1938; Graves 1984). Tynes (1999) noted that pot-bellied pigs may attempt to upend their water bowls so that they can play or soak in the water, and this author stated that heavy, non-tip bowls are needed to prevent this. Similar recommendations have been given for farmed pigs:

> "Placement of the waterer in the fenceline, without shelter from the sun and with a concrete slab beneath will discourage swine from creating a wallow underneath the waterer. Placement of gravel, large rocks or other similarly rough materials around the slab and diversion of all runoff water from the nipple waterer to the outside of the enclosure will further help to prevent sows from creating a wallow around the waterer" (Dellmeier & Friend 1991).

Abell (1947) recommended that windbreaks should be planted outside the fence, so that pigs cannot root up the ground and make wallows beneath the trees. Imes (1920) suggested that pigs, once they have become familiar with the wallows, will continue to use wallows after they have been supplemented with aversive substances like crude petroleum floating on the water. In those days, crude petroleum was recommended as a measure to control parasites, but it has also been used as a repellent to deter pigs from tail biting, which is a highly motivated behaviour once an outbreak has started (Zonderland 2010). Horrell *et al* (2001) observed that, although a basic wallow was dug out by a tractor with fore-end bucket to ensure the existence of a good wallow, the sows still rooted it out to a much greater depth. In fact, when rooting is prevented by nose rings, wallows were only half the depth of those in paddocks with unringed sows (Horrell *et al* 2001). Van Putten (2000), finally, stated that if presented with a pool of fresh clean water and a heap of earth, pigs will work hard to shove the earth into the water, creating a genuinely sticky and muddy substance. These observations indicate that pigs may have a demand for wallowing (but it cannot be specified exactly under which conditions and to what extent). Overall, this weighting category generates a positive loading ('+').

Importance of wallowing for pig welfare

This paper provided the first systematic account of the welfare importance of wallowing behaviour for pigs using a semantic-modelling approach. Taken together, the information presented in this paper leads to the suggestion that wallowing is important for pigs, especially when all its possible functions, including thermoregulation, are included in the formulation of the attribute as was done in this review. This does not (yet) imply that wallows should be provided ethically, nor that wallows generate a lot of added welfare when other (cooling, scratching, rooting and resting) facilities are available. It means that the welfare consequences, as (probably) perceived by the animal itself (Bracke *et al* 1999), appear to be considerable when the available information related to the various weighting categories is analysed in relation to both the

Table 1 Example attributes to illustrate welfare assessment.

Attribute	Best level	Worst level
Wallowing	Ideal mud pool	No pool
Food	Sufficient, nutritious food	Periodic deprivation (as in nature)
Foraging substrate	Fresh long straw	Barren pen
Social contact	Family group	Individual housing
No castration	No castration	Castration

Table 2 Weighting of several attributes to illustrate how their welfare importance can be assessed using semantic-modelling principles.

Weighting category	Wallowing	Food	Foraging substrate	Social contact	No castration
Pain and illness	-?	-	-		-
Survival	--	---	-		-?
Fitness	-?	--	-	-	-?
Stress	-?	---	-?	--	-
Aggression	-?	--	-?		*
Frustration and avoidance	-?	--	-	-	-?*
Abnormal behaviour	-?	--	--		
Natural behaviour	++	++	++	++	+?
Preferences	+	++	++	+	
Demand	+	+++	++	+	
Total weighting	9	22	13	8	4

Dashed line divides negative (-) weighting categories (above) and positive (+) (below). Two-point scales were used, except for 'Pain and illness', 'Survival', 'Stress' and 'Demand' which had a three-point scale.
? indicates a tentative loading. This was counted here as half a weighting point. Total weightings are summations of +'s an –'s.
* The best level ('No castration') has serious welfare problems too, especially sexual frustration, increased aggression and skin lesions (pain). This counterbalances the loading on the worst level (fear and pain of being castrated). To some extent this also applies to social contact (as pigs in groups may be aggressive towards each other).

best possible level ('an ideal mud pool') and the worst possible level ('*status quo*', including, eg no cooling facilities despite occasional hot weather). This analysis reflects a large, perhaps even very large, discrepancy between the way pigs actually perceive their environment under standard/poor conditions (*Istwert*, ie perceived actual state) compared to how they would ideally like their world to be (*Sollwert*, ie set-point; Anonymous 2001).

Most weighting categories loaded on wallowing, both positively and negatively. Inadequate or absent wallowing facilities may have a negative impact on pain and illness through reduced protection from sunburn, wound healing, ectoparasite removal and thermoregulation during general illness. It may also reduce production and survival, especially through heat stress caused by warm (and humid) climatic conditions. It may also compromise other aspects of fitness (eg fight and flight responses), enhance abnormal behaviour (pen soiling), stress and 'frustration and avoidance'. Because these weighting categories load on wallowing mainly through negative welfare, they were given negative (–) scores. Conversely, wallowing *in optima forma* (the ideal mud pool) is also important for positive welfare, because it allows natural behaviour with a phylogenetic basis and seems to be a preferred behaviour that is even 'demanded'. These weighting categories generated positive (+) scores.

Formally, the weighting factor for an attribute can be calculated as the difference between the sum of the loadings of each weighting category (Bracke *et al* 2002a). The present review did not allow such a calculation, because it required a comparably detailed review of other attributes for comparison. Based on existing experience in semantic modelling (see Bracke *et al* 2002a,b, 2008), however, it is expected that the weighting factor for wallowing *in optima forma* is probably relatively high. This may be illustrated in a tentative comparison with several other welfare attributes.

The attribute 'Social contact', for example, is generally considered to be important for pig welfare. It has been incorporated explicitly in the main definition of the freedom to express 'normal' behaviour as living 'in the company of the animal's own kind' (FAWC 2009), and it has been

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implemented in welfare legislation in Europe. For welfare assessment using semantic-modelling principles, a statement about natural ('normal') behaviour, eg 'pigs are social animals', provides a threshold loading, ie it is regarded as (just) sufficient to generate a minimal welfare loading. Being social animals implies, for example, that 'pigs tend to organise in social groups when given the opportunity'. This provides a first step in loading on the attribute (when, as it were, nothing else is known yet about the attribute; Bracke *et al* 2002a). When 'living in groups' is relevant because pigs are social animals, then wallowing must be equally relevant when pigs are 'wallowing animals', other things being equal.

In semantic modelling, the weight of an attribute increases when more information, especially about other weighting categories, 'load' onto it, ie when more scientific information about effects on welfare-performance measures is available. For example, wallowing in pigs is conditional, eg pigs wallow especially above certain ambient temperatures. Similarly, social contact is conditional, eg around farrowing sows isolate themselves from the group (SVC 1997). Differences in the incidences, duration and intensity will affect the loading. For example, since social contact affects most of the pig's life, whereas wallowing is relevant only for part of the year in temperate climates, this makes social contact more important (in this respect). Conversely, while 'wallowing' may be life-saving (in the case of severe heat stress), no such loading applies to 'social contact' (as isolated pigs do not die from being isolated). In addition, loading is also derived from a relation to stress for both 'wallowing' and 'social contact'. As a general rule, wallowing reduces heat stress, but social contact does not only reduce stress (eg stress that would result when individuals are isolated), but social contact may also enhance stress (eg due to aggression and mixing of animals). Such considerations are systematically made in semantic modelling in order to derive welfare weightings of attributes like 'wallowing' and 'social contact'.

In order to illustrate further how the weighting across weighting categories in semantic modelling works, Tables 1 and 2 present component scores and overall scores for selected attributes. The tables do not provide final weightings. They are intended primarily to provide an illustration of modelling principles. The scores are tentative and based on the opinion (perception/expertise) of the authors of this paper. The attributes have been chosen so as to generate some sort of scale (with both positive and negative controls, 'Food' and 'No castration', respectively) on which to assess 'Wallowing' (which is the objective of this paper). For further comparison, two attributes ('Social contact' and 'Foraging substrate') have been added as examples of (more) ethological requirements. In line with previous modelling, loadings depend on the range of the scale and the weighting categories. The scale is specified in the formulations of the best and worst levels (Table 1). The weighting categories affect loadings in virtue of their (potential) impact on welfare and as a general rule some weighting categories (eg pain and illness, survival, stress-physiology and demand) can generate a higher 'loading' than other weighting categories (Bracke *et al* 2002a). This is expressed in Table 2 as a difference in scale (ie 3-point vs 2-point scale). Overall, weights were calculated as the sum of the loadings of negative weighting categories (which act on the worst level of each attribute) and the positive weighting categories (which act on the best level; see Bracke *et al* [2002a] for a formal expression of the summation principle).

Table 2 shows that the attribute 'Food' is most important for pig welfare. Food is necessary for biological functioning (including survival), and it is generally recognised as a gold standard in consumer demand studies (Dawkins 1983). In fact, the value of food may be 'overrated' because of intensive selection for increased production efficiency (pigs have even been labelled 'neurotic' in this respect; Spinka 2009). This could imply that other, more ethological needs may be underrated, such as play (Lawrence 1987) and perhaps wallowing (Bracke 2011). More importantly, it should be noted that 'Food' was defined rather widely (as was done for all attributes including 'Wallowing'). The scale can also be defined more narrowly, eg by defining the worst level in terms of the nutritional value of food provided in current husbandry conditions. In that case, the importance of the attribute 'Food' is considerably reduced and expresses scope for improvement, rather than overall welfare importance.

Also included in Table 2 is 'Foraging substrate' (straw). This is a very important welfare attribute for pigs, because it has a clear association with tail biting (which is not only an abnormal behaviour, but also painful) and with tail docking (which is a routinely performed mutilation to prevent tail biting in current husbandry conditions; EFSA 2007b; Zonderland 2010). Straw may also provide resting comfort and provide a warm lying area when it is cold, but these aspects were not weighted in Table 2.

'No castration' was included as a negative control. While castration evidently involves (possibly intense) pain, its duration is very short compared to the welfare impact of the other attributes. In addition, when boars are not castrated this may result in sexual frustration, mounting, aggression, skin lesions, perhaps even tail biting (eg Rydhmer *et al* 2010), even (perhaps especially) in enriched pig pens. As a consequence, the overall welfare benefit of 'No castration' is probably relatively small (perhaps even negative). Furthermore, Table 2 shows that the welfare impact of 'No castration' is mainly through the negative weighting categories, whereas the other attributes also have positive weighting components.

To some readers, the low weighting of castration may be surprising. Non-castration is one of the main pig welfare issues in the European Union at present, much more so than the need to provide foraging substrate (and to stop tail docking and tail biting). This probably relates to human perception (empathy), intrinsic value and economic interests, but these aspects fall outside the scope of this paper.

Finally, Table 2 shows that wallowing generated a higher overall score than 'Social contact'. This surprising result may be explained by similar reasons (especially economics). More importantly, in relation to the primary function of Table 2 of illustrating semantic-modelling principles, it should be noted that the error margin around the overall scores is considerable due to the fact that component scores are tentative. In addition, the attribute 'Wallowing' was widely defined so as to include heat stress. When this aspect is provisionally taken out of the calculation, this would, by and large, remove the two minus scores under the 'Survival' weighting category. If so, the overall weight of 'Wallowing' would be slightly below the importance of 'Social contact'. Note that this still indicates that wallowing is probably much more important than has been recognised, as indicated by the fact that legislation has been drafted to ensure social contact for pigs while wallowing is not even generally perceived to be a welfare issue.

This section illustrated the weighting procedure in semantic modelling and included weightings based on the subjective assessment of the authors. More detailed analysis of related attributes would allow a more properly quantified and accurate weighting of the attributes. It is unlikely, however, that this would lead to a substantial modification of the conclusion that wallowing *in optima forma* is important for pig welfare.

Wallowing in current pig husbandry

The sixth and last step in semantic modelling involves an assessment of the (housing) system under consideration. In this paper, the current husbandry conditions in The Netherlands are used as an illustration. The attribute 'Food' may serve as an example. Under current husbandry conditions, pigs are normally provided with nutritious food. This implies that the actual situation for 'Food' is considerably better than the worst level which was specified in Table 1 as 'periodic deprivation (as in nature)'. By contrast, the worst level of the attribute 'Wallowing' was defined in close relation to current housing systems. Subsequently, scientific information was reviewed about the weighting categories. This included information from hot environments. The question then is whether and to what extent pigs kept under normal Dutch conditions would use ideal wallows when provided.

The available information to answer this question is extremely limited. Wallowing will depend on the quality of the wallow, prevailing environmental conditions and on animal-based variables (such as health status, [re-] productive status and activity levels).

Under hot conditions reported incidences of wallowing vary from seven times a few (between 1 and 9) min per day in artificial water baths of limited size (Huynh *et al* 2006) to a total duration of about 3.5 h per day in outdoor sows with access to spacious mud wallows (Sambraus 1981). An intermediate duration (7% of the total time budget) was reported by Johnson *et al* (2008) for lactating sows under extremely hot conditions (summer months in Texas, USA). By contrast, McGlone (1999) stated that during very hot weather pigs may stay in the wallow for very long periods of time, leaving only for necessary activities, such as feeding and nursing. Vestergaard and Bjerg (1996) reported that fattening pigs provided with wallows (100 × 40 × 5 cm; length × width × depth), filled with water, showed about eight times as much wallowing behaviour (rooting followed by laying down on the side) as pigs kept in similar pens without wallows (straw-flow pens, 0.78 m^2 per pig). When kept at around 30°C these pigs wallowed about three times as much as when kept at 18°C (Vestergaard & Bjerg 1996).

Several authors specified 'critical' temperatures as of which wallowing was clearly shown or recommended. To assess the potential usage of wallows, this information may be linked to present conditions on Dutch farms. This can be illustrated for both pregnant sows and growing/fattening pigs.

Sows appear to be motivated to wallow above 20°C (Sambraus 1981) and McGlone (1999) recommended providing a wallow to outdoor sows as of about 21.5°C. Since outdoor animals must deal with solar radiation as well as ambient temperatures (which are routinely measured in the shade), pigs housed indoors may not need to wallow as much as outdoor sows kept at similar temperatures. However, if we take the recommended temperatures as a starting point for potential benefit to the pigs, recent measurements repeated four or five times throughout the year on four Dutch farms indicated that pregnant sows were mostly kept above these temperatures (namely above 22°C in 12 out of 19 recordings and above 20°C for 15 out of 19 recordings; range 18.1–26.1°C; Mosquera *et al* 2010a). Therefore, in The Netherlands, pregnant sows seem to be kept normally at temperatures at which wallowing can be recommended for welfare reasons.

For growing pigs, Andresen and Redbo (1999) observed wallowing as of 22.2°C. Olsen *et al* (2001) reported that growing/fattening pigs used the wallow for lying with temperatures ranging from –4 to 24°C (where temperatures exceeded 18°C in only 5% of observations), with increased use duration when temperatures exceeded 15°C. As indicated earlier, EFSA (2007a) reported frequent fouling of the lying area when ambient temperature rises above 25°C with pigs of 25 kg and above 20°C with pigs of 100 kg.

Recent measurements, repeated five times throughout the year on eight Dutch farms, indicated that growing and fattening pigs were mostly (n = 41 out of 42 recordings) kept at temperatures above 22°C (range 20.1–27.6°C; n = 32 instances above 24°C; n = 23 instances above 25°C; Mosquera *et al* 2010b). This would suggest that in The Netherlands growing/finishing pigs are frequently kept at temperatures at which wallowing could be recommended.

In addition, at least three further points may be considered. Firstly, the comparison above indicates that current thermal conditions may have been optimised for production efficiency (with an emphasis on passive resting), and that this may differ considerably from a welfare optimisation (with an emphasis on behavioural activity). Secondly, while modern pig farms have fairly high levels of control for 'average' thermal conditions (and could perhaps reduce temperature set-points), there are very limited opportunities for individual animals to accommodate divergent individual needs. Accordingly, some pigs may have a considerably increased need for wallowing and for others this need may be reduced. This implies that current husbandry conditions, which are often regarded as meeting the basic needs of the animals, may not be satisfactory in satisfying the needs of individual animals. Finally, pigs may be motivated to wallow for other reasons than thermal comfort, eg they may wallow for body care, in cases of illness (wound healing, cooling, resting comfort) and after activity (eg after feeding, play, transport and mixing of pigs). Transport and fixing of animals is frequently practiced and in these cases wallowing needs are likely to be enhanced.

Overall, this suggests that pigs (growing/fattening pigs and pregnant sows) kept under normal Dutch thermal husbandry conditions could make considerable use of proper wallows when provided. Of these categories, newly mixed pigs, older fattening pigs and the pre-farrowing sows would probably use wallowing facilities the most (Vestergaard & Bjerg 1996; Buckner *et al* 1998). This may also apply to lactating sows, which are normally kept under very warm conditions (because of the higher thermal requirements of the piglets).

Further research, especially more quantified research, is needed to assess the importance of wallowing for pig welfare in more detail. This also applies to many practical problems which remain to be solved when farmers would actually want to provide wallowing opportunities for pigs, including hygiene and cost aspects. Closely related to these research questions, however, are ethical questions about the acquisition of knowledge and about the desirability of technological developments.

Ethical implications

This paper suggested that wallowing *in optima forma* is important for pig welfare. It also specified what ideal wallowing facilities should look like and that these are absent in current husbandry conditions. This review did not discuss alternatives for wallowing (eg alternative cooling, rooting, resting and body care facilities). It is not possible, therefore, to answer specific ethical questions about the need to provide wallowing facilities for pigs. At the same time, it seems unethical to continue to ignore the subject. The question then arises how best to deal with practical questions related to wallowing. Wallowing is a very sensitive issue, because it may be perceived as a threat to stakeholder interests, such as economic, ecological and food safety concerns. Financial margins on pig production are generally too narrow to perhaps even think about providing wallowing facilities for pigs. This may explain why in recent textbooks and scientific reviews, especially on intensive pig farming, wallowing has almost been 'forgotten' (Sambraus 1981; Spinka 2006; Bracke 2011). This implies that in order to succeed stakeholder sensitivities must be overcome.

In a classical approach to providing wallowing opportunities for pigs, the various questions would logically be separated and sequentially studied. Such questions include scientific questions (how important is wallowing for pigs?), technological questions (how to solve practical problems related to hygiene, costs, environmental footprint and food safety?; see also Callaway *et al* 2005; Jenn-Chung Hsu 2009) and ethical/political questions (do we need to provide pools to improve welfare?). The main disadvantages of such an analytical approach, however, include a tendency for research activities to be inconclusive and/or generate narrow solutions that do not satisfy the stakeholders involved.

Therefore, an alternative approach is suggested to enhance 'ethical room for manoeuvre' related to wallowing in pigs. This approach has been developed in applied ethics based on the observation that ethical views tend to co-evolve with technological developments. This implies the need for a conception of ethics as deliberative and experimental (Korthals 2004, 2008a,b; Driessen 2007). In this activity, various stakeholders are involved, including ethicists, applied ethologists, veterinarians, designers, farmers and pigs, working on ethical, scientific and technological priorities, based on formulated questions and answers in an ongoing process of interpretation and innovation.

For example, the development of the milking robot (automated milking system) has triggered ethical questions about permanent indoor housing of dairy cattle and about their ability to decide for themselves when it is time to be milked (Heutinck & Driessen 2010). Even early designs of technological innovations, such as the conception of the 'pig tower', may trigger renewed ethical thinking and generate a process of co-evolution of designs and arguments (Driessen 2007). This suggests that ethical issues related to wallowing can be approached by charting ethical considerations against the background of historical conditions and societal development.

For example, Sambraus (1981) noted that wallowing pools have been normal features of pig husbandry in the past (see also Dettweiler & Műller 1924; Schmid 1963). Early in the 20th century, pigs were normally kept on pasture with access to mud wallows during the day in summer. In the late 1930s, new pig houses were designed, allowing pigs outdoors on concrete floors, often with concrete wallows (Mayda 2004). With increased intensification these features disappeared and pigs were reared indoors on concrete slatted floors without wallows. Nevertheless, wallowing facilities have continued to be provided in organic production, even though in EU legislation wallowing has not been prescribed, neither for intensive, nor for organic production. Local prescriptions, however, exist, such that, for example, most organic sows in The Netherlands have access to wallows in summer. Regarding intensive production, Denmark has adopted legislation requiring the installation of cooling facilities for pigs (Danish Pig Production 2007; http://vsp.lf.dk/Publikationer/Kilder/lov_bek/104.aspx). The installation of sprinklers is now common in Denmark and experts advise using them at ambient temperatures as of 15°C. Perhaps sprinklers are an alternative to wallowing in mud. Perhaps proper wallowing facilities with mud will be a next step toward sustainable pig production. Furthermore,

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in some countries, wallowing facilities are provided in intensive systems, eg in China (Jenn-Chung Hsu 2009) and Brazil (Zonderland & Enting 2004).

A detailed review of existing experiences could support future developments, which include an increasing need for positive pig welfare in the market and a need to perhaps meet the challenges of global warming. Working on wallowing facilities for pigs may then be regarded as an opportunity rather than as a threat.

Policy-makers, scientists and stakeholders in the production chain (eg retailers) are showing increasing interest in communication about positive aspects of welfare (Boissy *et al* 2007; LNV 2007; FAWC 2009). Wallowing may provide a unique opportunity in this respect, because, contrary to most other ways of providing enrichment (eg through foraging, exploration and play), it is associated with reduced behavioural activity (mostly passive resting; Bracke 2011). This may match better with the objective of production efficiency than increased activities, such as play and foraging. In the short term, communication about wallowing facilities for pigs may create new market opportunities for (part of) the organic pig sector, perhaps in an organic-plus segment, especially when combined with other special features, such as providing a cognitively challenging environment for pigs.

Also, for intensive production, positive communication about animal welfare is important, because negative messages (eg about poor welfare related to castration, tail docking and tail biting) may require about a five-fold increase in positive advertising to compensate for a loss in sales (Verbeke 2009). Perhaps, clever wallowing (-like) facilities can be designed for application in intensive systems to counteract the ongoing flow of negative communication about intensive pig production.

In conclusion, wallowing behaviour in pigs is sufficiently important to actively encourage stakeholders in pig production to reconsider the subject and to examine their 'ethical room for manoeuvre' in a co-evolutionary process. This involves the simultaneous development of feasible technological alternatives for 'mud baths', disclosure of animal motivations for wallowing and an appreciation of their ethical desirability. This is important for the transition towards completely sustainable systems in the future (Verburg 2008), which may fail without attention to potentially significant aspects of the animals' natural behaviour, such as wallowing in pigs (cf Lassen *et al* 2006).

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